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GALVANOPLASTIK;

OR THE PROCESS OF

COHERING COPPER INTO PLATES,

OR OTHER GIVEN FORMS,

BY MEANS OF

GALVANIC ACTION

ON COPPER SOLUTIONS.

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TRANSLATED FROM THE GERMAN EDITION,

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PREFACE.

The pages which I now submit to my readers contain such of my discoveries of the new application of the galvanic powers, as appear to be important with reference to practical and scientific individuals; and which, in some measure, already has become so. It happened, whilst I was in Dorpart, in the month of February, 1837, prosecuting my galvanic investigations, that I discovered a striking phenomenon which presented itself in my experiments, and furnished me with perfectly novel views. By an attentive observation and persevering pursuit of this phenomenon, I soon became convinced that in this simple fact there lay a completely new field of interest, which, by means of galvanic currents, we might be able to arrive at successfully; but it was only by very gradual steps that I attained a knowledge of the simple conditions on which the results were depending.

Towards the latter end of the same year, in consequence of the convocation, at St. Petersburg, of their Excellencies the Ministers, for the people's moral improvement, in which I was entrusted with the command of the most important labours, I was considerably interrupted in this pursuit: notwithstanding, however, I found intervals of time for occasional observations and experiments, which I could afterwards turn to advantage. After the termination of this interruption, the results of my proceedings appeared with more certainty; and having succeeded in removing many casualties from the process, I made communication of my discovery, accompanied by a well developed galvanic production, to the Royal Academy of Sciences, which was read in the Session of the 5th October, 1838, and first published in the *Bulletin Scientific*, No. 95. An abstract of the same paper afterwards appeared in the St. Petersburg *German News*, of October 30th, by means of which it obtained much greater publicity.

His Excellency the Minister for Moral Improvement, and President of the Academy, who had previously introduced it to that learned assembly, had also the kindness to place this *first* galvanic production before his Majesty, our Lord and King; and it was ordered that a second printed notice of my process should appear in the St. Petersburg *Russian News*, of the 24th December. On the 29th of the same month, a translation of that article appeared in the *German News;* hence, even so early as this date, the information of my discovery had spread rapidly through the medium of different languages. It also appeared, about the same time, in many foreign languages; as, for instance, in English newspapers, and scientific and other journals.* I purposely allude to these printed official documents, to prevent those who otherwise, from a knowledge of my discoveries, might be induced to proceed to experiments, and venture to refer to claims, by appearing to be totally ignorant of that previously done. The galvanoplastik process belongs to Russia exclusively. It was here that it originated, and here were its improvements acquired. The magnanimity of our Government, which always provides for the dissemination of useful knowledge, has given general publicity to this discovery in the most complete manner possible; and at the same time has bestowed a valuable present to every other part of Europe.

Galvanism is a mighty multilateral operating agent, which was discovered about the commencement of the present century; and now, above all other subjects, engages the attention of philosophers in every part of the world. Until now, this power was known only in the quiet study of the learned, and in the laboratories of the philosopher and the chemist; and now, for the first time, has it been made to advance and spread through an extensive circle of the arts, and proceed to the hands of the artificers and manufacturers. You, my readers, will become acquainted with a power whose phenomena may not, perhaps, be strange to you generally, but whose laws and management may appear to some of you too mysterious, or at least too complex, to be overcome. On this account I have thought it necessary to prepare, beforehand, a generally comprehensive representation of these laws ; and in order to understand it, you must favour me by laying aside all former prejudice, so that you may be sufficiently informed in the theory to enable you to overcome all accidents and difficulties that may present themselves, which, though tedious, and almost impossible to enumerate, may be removed by attention and activity.

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* The first information we had of Professor Jacobi's discovery was from our correspondent at Munich, in a letter dated February 5th, 1839. See "Annals of Electricity, &c.," vol 3, pp. 507-508.—TRANSLATOR.

I have already had experience, that men entirely without scientific cultivation, and without education, accomplished the galvanoplastik process, from the directions that I have imparted to them respecting the usual routine of manipulation of the galvanic apparatus. When, indeed, we consider that at this day almost every one is acquainted with the use of the lever, the screw, and the other mechanical powers—that everybody is acquainted with the pressure of air and water, and know how to explain the phenomena—that the advantages of fire and heat, and of the elasticity of steam, have become generally understood—that the complicated operations of chemistry, in the manifold industrious movements in the arts and manufactures, are carried on with facility and exactness ;—and if we look at all these powers and apparatus as they appeared at the commencement, and consider that they went out of the lap of the scientific philosopher no less complex and mysterious than the galvanic appears to be now, we immediately arrive at the conviction that the day is not far distant, indeed, is already at hand, when even this power, amongst the rest, will be cultivated to advantage by the industrious of all nations, and, like them, will henceforward yield profit in its turn. Hence it is, that as the other scientific inquiries have become established and promoted—as favourable operations and inquiries proceed unobstructed—as the mistrusts and jealousies, by which the practical man and the man of science are kept at a distance from each other, disappear ; and when every one ceases to refuse the other the full acknowledgment of his right of discovery—then will galvanism present a new example, that even the smallest grain of seed scattered by the philosopher, will, sooner or later, produce its full share of fruit.

In the publication of this essay, I cannot conceal that I have laboured under a peculiar anxiety; for I am well aware that the obstructions wherewith we are continually assailed in our inquiries, become, eventually, so familiar, that we hold them lightly and as mere trifles, and even entirely lose sight of the numberless troubles that attend experimental pursuits which led to the results; whilst a detail of those events would be extremely useful to the beginner. It is, however, my particular wish to place this essay before you as an easy and familiar whole; to facilitate the process, to prevent error, and to make the pursuit familiar; and, as the saying is, not to leave you under the necessity of making the entire school for yourselves. I have, on this account, taken some pains in choosing and deciding on principles; and I have also described the management of them as distinctly as possibly I can. Nevertheless, I have been unable to arrive at that degree of perfection that I could have wished, so that I must request you to apply to me personally, in order that I may shew you the apparatus and explain them more clearly; to make you familiar with many manipulations which could not, without prolixity, be exhibited in a written form; and to assist you generally with council and deed, whereby you may be enabled, without embarrassment, to practice this new art, and derive sure profits from your industry. I shall, hereafter, give public notice in the journals, on what days I may be consulted, either at my own residence or at some other place; where you will be received without distinction, and assisted in overcoming such difficulties as you may happen to meet with in this new source of employment.

It gives me great pleasure to have this opportunity of publicly acknowledging the favours and assistance which I have received from those illustrious statesmen, whose magnanimity is ever ready to promote the interests of science, and every branch of useful knowledge.

M. H. Jacobi.

St. Petersburg, March, 1840.

GALVANOPLASTIK.

If a common zinc plate be placed in a vessel containing dilute sulphuric or muriatic acid, it will dissolve more or less rapidly, and the developement of hydrogen, which in this case is not pure, will be known by the unpleasant stinking smell. If the zinc plate be withdrawn from the liquid, and some drops of quicksilver be poured on it, the liquid metal will spread all over it;* or, as we say in technical language, it will amalgamate, and the plate attains a silvery brightness. If we now again immerse the plate in the acid liquid, it will remain perfectly neutral and unacted on by it, and may be kept there for a considerable time without suffering loss of weight. If we immerse a plate of copper in the same vessel with the amalgamated zinc plate, but without touching, the condition of the latter is in nowise altered; but if we bring the two plates into contact with each other, either below or above the surface of the liquid, or even connect them by a metallic conductor, such as a wire or ribband of copper, brass, lead, or any other metal, we immediately perceive hydrogen in bubbles developed on the copper plate. But the zinc plate, when well amalgamated, has no perceivable developement of gas; nevertheless it gradually corrodes, and eventually becomes entirely dissolved. This, and similar phenomena which only occur between two different metals (I have chosen copper and zinc as an example), when brought together in presence of a fluid, indicate a certain peculiar force, which we call *galvanism.*

We have already seen that a common zinc plate, independently of the operation of the copper, becomes dissolved in the acid solution; and we know that that fact indicates a chemical process. The water with which the acid is diluted by the action of the zinc, becomes resolved into its constituent elements—hydrogen and oxygen gases: the latter combines with the zinc, and forms a compound which unites with the sulphuric acid, and sulphate of zinc is formed. The hydrogen is perfectly free, and escapes in the shape of gas. Similar decomposition also takes place by the galvanic influence, but with this difference in the nature of the action, that the oxygen, as before, combines with the zinc; but the hydrogen appears on the surface of the copper plate, and finding nothing to combine with, makes its escape.

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* This method of amalgamating zinc was first shewn by the Translator in 1830. See his "Recent Experimental Researches, &c."

I.

The apparatus represented by fig. 1 of the plate is usually called a *simple galvanic circle;* where *c* is a plate of copper, *z* a plate of zinc, *c v z* a wire or strip of metal which connects the two plates together, and *a b c d* a vessel in which they are immersed in the dilute acid. We will here just remark, that the purpose of such a piece of apparatus is occasionally, though but seldom, employed for obtaining a solution of zinc, which, as we have already seen, can be obtained by simpler means. But we shall only notice those operations which to us are of greater importance, and which are due to the connecting wire or other metallic piece which is used in place of it. Experience has shewn that the strength of the action is somewhat proportionate to the quantity of hydrogen liberated at the copper plate; but the bubbles of hydrogen which rise from the zinc, not only nothing strengthens the action, but, on the contrary, absolutely weakens it. If we employ common, instead of amalgamated zinc, in a galvanic circle, there will be a compound or mixed action—the chemical and the galvanic—which conjointly dissolve the zinc. The violence of the effervescence, and the rapid dissipation of the zinc plate, are not, in such cases, any standard of the galvanic power, which is indicated only by the quantity of zinc dissolved by virtue of the combination of the copper with the zinc plate. The dissipation of the zinc, which is brought on by itself alone, may be considered as a useless loss; at least in reference to the galvanic activity which we wish to produce. It follows, we hold, from these considerations, that the galvanic power may be measured by collecting the hydrogen in a glass tube, whose capacity is already ascertained; or we may arrive at the same thing by ascertaining the loss in weight which the zinc suffers in a given time. These measures, however, are somewhat uncertain; because, after the zinc is even amalgamated, accidental circumstances occur by which small quantities of zinc become dissolved in the acid solution, which have no reference to the galvanic action. If, instead of the acid, we take solutions of salts, such as common salt, sal-ammoniac, glauber salts, &c., the zinc itself, though not amalgamated, does not become corroded; and it is only when in galvanic combination with copper that it suffers any loss, and the loss which it then suffers has a close relation to the quantity of hydrogen liberated at the copper plate.

II.

We have hitherto said, for example, that zinc and copper have this power of galvanic action; but it is to be understood, that a similar action is produced in a greater or less degree by a combination of any pair of dissimilar metals; and experiment has shown that they observe a certain uniform relationship, according to that represented by the following series, which we have introduced in the usual way:—

PLATINUM.
GOLD.
SILVER.
QUICKSILVER.
COPPER.
LEAD.
TIN.
IRON.
ZINC.

In this series the metals are placed according to their electrical characters, in the same relation to each other as zinc has to copper; so that any one of them operates as *zinc* to all those above it, not however in point of energy, but only of the kind and manner of action; and the more distant from one another any two metals stand in the series, the greater the galvanic action they will develope. Hence, a galvanic series of platinum and zinc is more powerful than one of copper and zinc; and the latter, again, more powerful than one of lead and zinc, &c. It is not to be understood, however, that the power of any two metals in the table depends upon the *number* of intermediate ones, because a galvanic series of platinum and iron is much feebler than a series of copper and zinc; although in the former case there are six intermediate metals, and in the latter there are only three. Platinum and gold, or gold and silver, or silver and copper, combined together in a voltaic series, give but very feeble action. I must here mention, however, that the behaviour of the metals towards one another is, in some cases, altered by the employment of several kinds of liquid for the exciting medium; but this is to be considered only as an exception, which does not frequently come into operation.

Besides these principal metals, there are other substances, which, as regards their galvanic effects, are very considerable. Of these, however, the principal, in a practical point of view, are charcoal and plumbago; but the latter can only be considered as a peculiar quality of charcoal, usually containing a portion of iron. Both these substances stand higher in the scale of electric bodies than platinum, so that a galvanic series of plumbago and zinc is the most powerful hitherto known.

Before proceeding further, I will avail myself of this opportunity of addressing myself to the industrious part of my readers. You have seen, in the introduction to this work, that to you this science is capable of performing a very important service, which it offers in a very disinterested manner; it expects, however, that you, in return, will let no opportunity pass unnoticed in which you can be useful to its promotion. By this means you at once rank amongst the best and most useful of your fellow-citizens. On this account I have here mentioned the excellent properties of graphite, in reference to galvanic action. It is difficult, however, to procure this substance in large masses or plates; it is, therefore, generally produced by some artificial means. It may be formed by smelting it with iron in a highly-heated furnace, by which means we find it in the character of cast-iron; which, as is well known, is but another combination of iron and carbon. We have only other experiments to make, adding more carbon than is usually contained in cast-iron, to arrive at a metal whose galvanic properties would be equal to those of platinum.

Such cast-iron, in consequence of its containing so great a quantity of carbon, might possibly be but of very little service for any other purpose. In galvanic apparatus, however, as no great resistance has to be withstood, the compound would not require to be of any peculiar firmness of cohesion. A compactness sufficient for it to be cast into plates, or, perhaps, cylindrical vessels, might be all that would be required. It might be preferable to give it such a property that none of the graphite would be acted on by the nitric or the sulphuric acids, whether concentrated or diluted. It is well known that the object in view may be obtained by a species of cementation; or by remelting cast-iron, with additional carbon, in closed vessels. In the laboratory of the chemist or physician, the difficulties and inconveniences to be met with in such a course of experiments, would be too great for the undertaking; but in the iron-foundery, where every requisite is at hand, the good-will of the proprietors, or of the managing officers, would be the only additional trifle required. Should any person find this statement of facts sufficiently interesting to induce him to proceed to experiment, and that he succeeds in forming a mixture of iron and carbon that will become serviceable for galvanic purposes, it would be satisfactory to me to have this proof obtained; even on my own account it would be gratifying to have my views submitted to the requisite trial.

But were such an electric property as this to be met with in a metallic mixture or alloy, we could not, from that circumstance alone, establish any general rule for facilitating the pursuit of still better compounds, whilst furnished with only a few experiments; for it must be borne in mind, that the electrical character of the alloy does not always take a place between those metals of which they consist, but more frequently they stand either much higher or much lower in the series. Such, for instance, is the case with brass, which mostly acts, in galvanic arrangements, either quite as well, or even better than copper, which is one of its constituents. On the other hand, also, either amalgamated zinc, or a compound of zinc and quicksilver, acts even better than zinc alone, although the quicksilver itself stands high in the galvanic series. And I have discovered a still better compound than quicksilver and zinc, which consists of 38 parts of quicksilver, 22 parts of tin, and 12 parts of zinc. Nevertheless, in such alloys as these, where too much quicksilver is introduced, the disadvantage is, that they are extremely brittle, and have but little coherence.

III.

The following are the most essential circumstances by which the power of galvanic arrangements is influenced :—

1. The size of the plates as regards their surface.

2. The distance at which they are placed from each other in the liquid.

3. The strength and character of the exciting acid or saline solution.

4. The character and the length and thickness of the conductor which unites the zinc and copper plates.

5. The extent of the series, or number of pairs of plates contained in the battery.

Before we consider these circumstances more particularly, we will just touch upon some of the various phenomena which are shown by the galvanic powers themselves. Upon this point we know nothing further than what has hitherto been stated, excepting that we observe that the water of the exciting liquid in the battery becomes decomposed ; that the hydrogen is developed at the copper plate ; and that the zinc plate, or whatever is employed in lieu of it, dissolves in the liquid ; and furthermore, that these operations take place only when the metallic plates are connected with each other by a good metallic conductor, usually called the connecting wire or the connecting bow ; for as soon as the connection in any part of the circuit is interrupted, all galvanic action ceases.

As the galvanic activity terminates at the precise moment that an interruption takes place, it may be necessary to say a few words on that point.

Since, then, the uninterrupted conductor joining one plate to the other is the first condition of galvanic energy, it will be necessary to say a few words on that point. We will suppose, provisionally, that this conducting medium is metallic, and that it may be permitted to consist of wires or strips of various dimensions, and also of different kinds of metals : supposing in all cases that they are intimately bound, or otherwise fixed together in good metallic connection. This end is obtained very conveniently by means of solder; but it is sufficient that the ends of the conductors be made bright, and either twisted or rivetted together. If we are desirous of having a contrivance by means of which we can break and make contact with still more convenience, the clamp screw, (binding screw,) or small cups holding mercury, may be employed advantageously. The cups may be made of any convenient size, from hard wood or glass, or even pasteboard, and fashioned in any way the experimenter thinks proper. If metal be used for this purpose, it must be either copper or iron. Brass, in time, corrodes by the quicksilver, and lead and tin are shortly destroyed by its action; hence the iron or copper cups should not be soldered with soft solder, the hard solder alone being suitable for this purpose.*

Fig. 2 is a cup for holding quicksilver, and can be screwed firmly and immediately to a wire which is soldered to another plate of a galvanic apparatus. This figure needs no further explanation; and even but very little will be wanted to understand figures 3, 4, 5, and 6; where 3 represents a *single* clamp screw soldered to a wire; and the other, *double* clamp screws similarly connected with other wires. A broad strip of copper soldered to a clamp screw, as represented by figure 7, is preferable to wires; *a*, *b*, is a small brass or copper plate, in the middle of which it carries a small winding screw pin, partly seen above. The strip *e*, *f*, must have a hole or slit in the middle to admit the vertical screw pin, and then it is firmly screwed down by the nut. For preparations of this kind it will be advisable to have a good stock in store, and to have the binding screws with perforations of different dimensions, suitable to the various dimensions of the conducting wires that it may be found necessary to use and clamp together. The screw heads should also be both milled and cut for the introduction of a turnscrew, if found necessary. The milled head will be found very convenient for the first advances of the screw, which, in many cases, will require no aid whatever from the screw-driver.

In referring again to figure 1, which represents a simple galvanic circle, I will only remark, that we consider the galvanic energy to consist in a constant current of electricity, which sets out from the zinc plate to the acid solution, through which it passes to the copper plate; and from the copper it traverses the metallic conductor back again to the zinc, in the manner represented by the small arrows in the figure; and that we shall frequently avail ourselves, as we proceed, of the expression *galvanic* or *electric* current. Hitherto we have said nothing on these closed circles, further than that there is a developement of gas on the surface of the copper plate; that the zinc plate dissolves without effervescence; and that these effects immediately cease on the circle being interrupted, either by lifting one end of the conductor out of the quicksilver in the cup, or by any other means whatever. We can, however, observe some other very remarkable effects by the action of such a closed circle.

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* This remark would be perfectly useless when the cups are made out of solid pieces of metal, as is the custom in this country. I have used brass cups for many years, which are still as good as ever. They are amalgamated inside, which is a convenience, by preventing the mercury from being thrown out by those accidental jolts which so frequently dislodge it from wooden and other cups, to which it will not adhere.—TRANS.

Most of my readers are well aware that a magnetic needle, freely suspended, either upon a pin point or by means of a delicate fibre, directs itself nearly north and south. If we now consider that the conducting wire, which joins the copper and zinc plates in figure 8, is extended in the natural direction of the magnetic needle, N. S., we observe, whilst the circle is closed, that the needle turns aside from its first position, and that it immediately returns again when the circle is broken. The direction of this deviation is various, accordingly as the needle itself is placed *above* or *below* the conducting wire; and also, accordingly as the current traverses the wire from north to south, or from south to north. Figures 9, 10, 11, 12, explain the kind and manner of these deflections sufficiently to render it almost needless to add, that figures 9 and 10 represent them when the wire is *above* the needle, and figures 11 and 12, when the wire is beneath it.

It is an invariable rule, that the greater the deflection of the needle, the stronger is the galvanic power, or the more powerful is the electric current, which also stands in near relation to the quantity of the hydrogen liberated in a given time, or to the quantity of zinc dissolved. The magnetic needle is, therefore, a valuable instrument, by which the mere inspection of its deflections informs us of the energy of galvanic force. It is principally for this purpose that we shall, further on, make use of it: for the present we cannot dwell any longer on these highly remarkable electro-magnetic phenomena.

The next observation that we shall make on the connecting wire, is that of its becoming heated as soon as it enters into the galvanic circle. This heating power is greater in some proportion to the increase of the energies of the battery; but, at the same time, it depends, also, on the size of the conductor, and on the character of the metal of which it consists. The circumstances which prevail in the production of heat by galvanic arrangements are considerably entangled in complexity, and all that we can state in this place is, that with the common metals, a wire of platinum generally becomes heated to the greatest extent; and if it be not too long or too thick, it is easily brought to the highest glowing heat, and even fuses. In consequence of the heat becoming greater as the galvanic power increases, we are enabled to ascertain the power of the battery by the degree of glow produced in a thin platinum wire placed in the circle, though not with such precision as by the deflections of a magnetic needle.

Figure 13 represents a contrivance for heating the platinum wire, and requires but little explanation, further than that it consists of two stout cotton or silk covered wires, which are united at the upper extremities by a fine platinum wire of about half a foot long; and that, when used, the lower bright ends, x, y, are either *directly* or *indirectly*, by means of other wires, brought into connection with the plates of the battery. I will also remark, that it is convenient to have such *test wires* of various lengths and thicknesses, by means of which the power of any determined size of battery may be measured, and its required working order duly ascertained. I will only add, in this place, that a chemical energy may also be ascertained by means of a galvanic current; on which topic I shall treat pretty copiously further on, because it is this that forms the foundation of the useful part of the application of our subject.

IV.

In a former part of this work we have considered the galvanic energy under the form of a current, which proceeds with an uninterrupted circulation from the zinc, through the acid liquor, to the copper, and through the conducting wire from the copper back again to the zinc. The power which sets this current into motion depends on the natural electric condition of the effective metals of which the battery consists; and, as we have seen above, (Art. 2) this power is always greater as the metals are more distant from one another in the tabulated series. But this power experiences certain obstructions, or, as we frequently say, *Conduction-resistance (Leitungswiderstände*), which weaken the strength of the currents. If, now, we pursue an electric current along its channel, we shall find the *first* resistance that it experiences at the plane of contact, where it passes from the zinc to the liquid in the battery. A *second* resistance is experienced whilst passing through that liquid; a *third* when the current leaves the liquid to enter the copper plate; and a *fourth* in the conducting wire itself. All these resistances being added together and brought to a common unit, we have, by many experiments and observations, obtained the following principal law:—*The strength of the currents diminish as the sum of the operating resistances increase*:—So that, when this sum is double, the strength of the current is reduced to one-half of the original standard; and when the resistances are but one-half of the first unit, the strength of the current is doubled, &c. The determination of these individual resistances, however, is very difficult, and all that has been acquired is to obtain a general survey to which we can have some practical reference.

From the experience hitherto obtained the following laws have been determined:—

1. That all the resistances to transmission become *smaller* as the surfaces of the plates are enlarged.

2. The resistance presented by the liquid in the battery becomes *greater* as the plates are more distant from one another; and *smaller* the greater the transverse section of the liquid. This resistance also depends on the natural character of the fluid conductor; and, in general, it becomes *smaller* as the acid, or saline solution, employed in the battery, is more concentrated.

3. The resistance of the conducting wire likewise depends upon the character of the metal of which it consists, and operates, more-

over, *in proportion to its length, and inversely as the transverse section*, whether it be a wire or a strip.

We thus see that the power of a single pair of plates can be strengthened only by lessening these resistances; which can only be accomplished by increasing the transverse dimensions of the conducting wire, enlarging the plates, and bringing them nearer to each other, and, finally, by strengthening the liquid of the charge. With the two latter circumstances we soon arrive at certain limits. For instance, the plates must not be permitted to touch one another in the liquid; and there are also good reasons to suppose that they ought not to be placed nearer to each other than about a quarter of an inch. There are also disadvantages by employing too strong a charge, by facilitating crystallization when the fluid is saline and too saturated, in which case the action becomes diminished. If concentrated sulphuric acid be used in the battery, we obtain scarcely any action; but if the acid be diluted with from four to five parts of water, the action becomes very great, &c.

It appears from hence, that when the resistance of the conducting wire is not too great, the best means to increase the power is to enlarge the plates; which we will endeavour to illustrate by an example. If we allow the power which sets a current in motion from a single pair of copper and zinc, of one square inch surface, to be represented by the number 1, or as an unit of force, the resistances of that pair of plates themselves may be equal to the resistance presented by a copper wire of 4000 feet long and one-tenth of an inch thick. Moreover, if this single circuit be closed by a conducting wire of 1000 feet long and also one-tenth of an inch thich, the power of such a pair of plates will, therefore, be as the fraction $\frac{1}{4000+1000} = \frac{1}{5000}$. If, now, the conducting wire be shortened to about one foot long, the power will be increased to $\frac{1}{4001}$: and, finally, when the plates, by means of solder, are immediately joined together, the power becomes increased to $\frac{1}{4000}$. By shortening the conducting wire in this case, the power is brought from $\frac{1}{5000}$ to $\frac{1}{4000}$, or increased about one-fourth.

If we increase the size of the plates to 10 inches a side, so as to have 100 square inches of surface, the power obtained is $\frac{1}{40+1000} = \frac{1}{1040}$. Had the plates 20 inches a side, or 400 square inches of surface, we should obtain a power of $\frac{1}{1010}$; and if they were 80 inches a side, or 6400 square inches of surface, the power would be $\frac{1}{1000+\frac{5}{8}}$, or nearly $\frac{1}{1000}$. We learn from these data, that by increasing the magnitude of the surface the power advances as far as $\frac{1}{1000}$, or rises to a fivefold extent. But in order to strengthen the power of the current, we must not only increase the extent of the surface of the plates, but, at the same time, shorten the conducting wire also. Hence, for instance, we obtain a hundred-fold current by 10-inch plates and a conducting-wire of 10 feet long: a four-hundred fold current by 20-inch plates and a conducting wire of 2½ inches long, &c. Indeed, the power rises as decidedly by shortening the conducting wire as by augmenting the surface of the plates. We must, therefore, not be surprised that little or no power is gained by an increase of size in the plates, when the conducting wire is long and thin. If, however, circumstances be such, that the connecting wire must be 1000 feet long, and the battery consists of ten-inch plates, we may augment the power a hundred-fold by using 100 such wires side by side for the conductor, or by closing the circuit with one wire 1000 feet long and one inch thick.

V.

When we have more than one pair of plates at command, we have an opportunity of combining them in different ways. In the first place I shall remark, that by combining all the zinc plates together into one parcel, and all the copper plates into another, *the operation of them is precisely the same as if only one single pair were used, whose surfaces were equal to the sum total of all the surfaces employed.* But when the copper plate of the first pair is combined with the zinc of the second, and the copper of the second with the zinc of the third, &c., and the extreme copper plate at one end of the series, and the extreme zinc plate at the other end, are united by the conducting wire, a very distinct effect is produced, differing from that obtained by the former mode of combining the metals. Fig. 14, plate viii., shews the former mode of combining the plates so that they may operate as a single pair; and fig. 19 shews the latter mode of combining them so as to act behind one another, or in series. I also wish to refer to figs. 15, 16, 17, and 18, as examples of combining twelve pairs in other different manners:—

Fig.	14,	the combination	as	1	pair of	12	times the surface.
,,	15,	,,	,,	2	pairs	6	,, ,,
,,	16,	,,	,,	3	,,	4	,, ,,
,,	17,	,,	,,	4	,,	3	,, ,,
,,	18,	,,	,,	6	,,	2	,, ,,
,,	19,	,,	,,	12	,,	1	,, ,,

The performance of these different dispositions of the plates is regulated by the following laws: *By the combination of a number of pairs, behind one another, or in series, the power of the plates themselves* (1) *of setting the current in action, and* (2) *of overcoming the resistances, will be in proportion as their number is multiplied.* We should, therefore, from the preceding examples of combining the plates, obtain the following rates of action:—

Fig. 14....
$$\frac{1}{\frac{4000}{12}+1000}=\frac{1}{1333}$$

Fig. 15....
$$\frac{2}{\frac{2.4000}{6}+1000}=\frac{1}{1167}$$

Fig. 16....
$$\frac{3}{\frac{3.4000}{4}+1000}=\frac{1}{1333}$$

Fig. 17....
$$\frac{4}{\frac{4.4000}{3}+1000}=\frac{1}{1583}$$

Fig. 18....
$$\frac{6}{\frac{6.4000}{2}+1000}=\frac{1}{3000}$$

Fig. 19....
$$\frac{12}{12.4000+4000}=\frac{1}{4083}$$

We have given the fractions in this page as they stand in the original; but it is obvious that some of them do not agree on both sides of the equation.—Trans.

We also here see, that by using a conducting wire 1000 feet long, we obtain the strongest action, by combining the plates into two pairs of six each; or, which is the same thing, when we use two pairs in series, each plate of which is six square inches. For other lengths of the conducting wire, it is obvious that other combinations of the battery plates would be more suitable. If, for instance, we had a conducting wire of 12,000 feet long, we should then obtain the strongest action by the combination represented by fig. 18, where six pairs of plates, of double the unit of surface, are combined in series. It frequently happens, however, that the combination which gives the greatest effect can only be discovered by direct experiment; by calculation, however, we find, *that the most advantageous disposition is that by which the resistance of the battery is equal, or nearly equal, to the resistance of the conducting wire.* It follows, therefore, as a practical rule, that when we wish to have a battery for all the various purposes of experiment, we must choose one with a sufficient number of pairs, and which can easily be convertible from any required number to any other required number of pairs or factors of the whole series. If, for instance, we had seventy-two pairs, we could, by proper arrangement, convert them into twelve different kinds of battery.

Notwithstanding the gavanoplastik apparatus requires no long conducting wire, I must say, that here, as decidedly as in those cases already mentioned, the resistance of the wire is directly as its length, and inversely as its thickness. *All such wires or strips of metal exercise a similar influence on the strength of galvanic currents, when we obtain the same quotient by dividing their length by the area of the transverse section;* or, which comes to the same thing, *when we divide the length of the wire by its weight.* If, therefore, without augmenting the battery, we wish to obtain the same degree of action through a conducting wire of double the original length, we must employ for that purpose a wire of four times the weight of the original one.

It has also been mentioned above, that the natural *quality* of the metals exercises an influence as decidedly as the *dimensions* of the conductor, which circumstance arises from the fact, that the various metals present a greater or a less resistance to the transmission of the electricity. The following table, the numbers of which express the quantity of resistance opposite a few of the most common metals, is founded upon the excellent observations of *Professor Lenz*:—

SILVER	9
COPPER	12
GOLD	15
TIN	36
BRASS	40
IRON	66
LEAD	80
PLATINUM	84

If, therefore, we wish to compare wires of the various metals with one another, we must multiply their lengths into the numbers expressing their resistance; and divide the product by the areas of their transverse sections. Hence, also, to use copper and iron strips of similar length and breadth, so as to produce a similar influence on the strength of the currents, the latter metal must be $5\frac{1}{2}$ times as thick as the former. I must here remark, however, that since for our present purpose the wire is never very long, the choice of the conducting metal is not of much consequence; for if no copper be at hand, we may use brass, or lead, or tin, for the uniting conductor: iron, however, in consequence of its easily rusting, and some other disadvantages which it presents, is not an economical metal for this purpose.

VI.

The *galvanoplastik* art depends upon the well-known remarkable properties of electric currents, by which almost all compound matter becomes reduced into its elementary constituents; the metals especially become separated from their solutions or combinations, and restored to their genuine metallic conditions. This property of the electric currents has been known since the beginning of the present century; but however highly important had been the scientific results emanating from that property of the currents, but little attention had been paid to the conditions by which the restored metals aggregate into masses. Frequently the metals were reduced into the shape of powders, sometimes into different sized crystals, and at others into lumps or congregated masses. The sportive freaks of chance appear to have been here the only rule; or, in other words, we were completely ignorant of the laws which govern these different formations ; and even now, the impediment to a true knowledge of these laws is not yet removed; but our information is so far advanced, that we know the conditions under which the copper can be immediately liberated from its solutions, and made to assume regular coherent plates of any required form.

I will first remark, that the galvanic apparatus which I have previously described, consisting of zinc, copper, and an acid, is not applicable to technical, nor to several scientific purposes. They are very changeable in their efficiency, and their powers, after a short time, become much enfeebled. However, these impediments are met by batteries of more modern date, which have come into general use. The dissimilar metals, of these latter apparatus, are not immersed in one and the same liquid, but in two different liquids, which are separated from each other by a porous wall or diaphragm, which the electric current percolates. The order of arrangement of such an apparatus is represented in fig. 20, where *a*, *b*, *c*, *d*, is a reservoir which, by a porous diaphragm, is separated into two cells. One of these cells is filled with a diluted acid, or saline solution, in which the zinc plate Z is immersed ; in the other cell the copper plate K is placed with a solution of sulphate of copper, or some other cupreous salt. Both plates are joined by a conductor, and form a galvanic circuit.

It will be remembered, from what has already been said, that with the common apparatus hydrogen is developed on the surface of the copper plate, and the zinc dissolves in the acid solution, so long as the circuit is closed. The dissolution of the zinc also takes place in the new apparatus; but the hydrogen does not appear on the copper plate, for it returns back and liberates the copper in a metallic state from the solution, and reduces it on the surface of the copper plate of the apparatus. Notwithstanding the difference in the constancy of action of this form of battery and the common one, however, which, by the former may be continued in uninterrupted activity for days or weeks together, the same laws of action, already discussed and explained, apply to both kinds of apparatus. In the year 1837, whilst in Dorpart, I had a series of experiments to carry on, upon the strength and duration of galvanic currents produced by an apparatus constructed upon similar principles; but instead of copper plates I furnished myself with copper cylinders, surrounded by animal bladders, for the purpose of keeping the liquids separate. As these bladders became damaged by use they were taken out, and gave occasion to inquire into the form in which the copper was reduced. It was found on the surface of the copper cylinders, and in the inner folds of the bladders, partly in thin bars and partly in large and small corns of a crystalline texture, which to those beneath shewed not the least attachment. Afterwards, however, whilst continuing to remove these corns, &c., it was found that they adhered more closely together, and required some force to separate them: it was also found that the copper cylinder itself was completely covered with a layer of reduced copper, which, to my astonishment, was removed in large well-connected plates. As no mention had hitherto been made of such regular formations of reduced copper, these corns, &c., were held of a high interest.* I must confess, indeed, that I was myself surprised, as I remarked at the time, that some fine file marks and indentations from hammer-blows, which were conspicuous on the surface of the copper cylinders, had, with the greatest degree of accuracy, given corresponding forms to the plates of reduced copper. This remarkable phenomenon was a strong proof of the conformation to the law by which copper is capable of being reduced, and which could not have been expected from the ununiform productions which had previously been obtained. As the reduced plates acquire a certain degree of connection and firmness, there were hopes that, by a discernment in their management, these properties might be obtained in a still higher degree: and, finally, this humid method of forming copper plates on the surface of the cylinders, by galvanic action, immediately held out a practical result worthy of pursuing. How and by what manifold experiments these expectations shall be conformed with, and what will be acquired, in the course of performance, beyond that already done, cannot, in this place, be mentioned, where merely the description of the proceeding and the methods hitherto given are intended.

It appears, therefore, that firm coherent copper may be reduced from its solution by the galvanic current. For this purpose we employ an apparatus similar to that formerly described. It is represented by fig. 21, where *a*, *b*, *c*, *d*, is a wooden trough or reservoir, made completely water-tight by a lining of asphaltum or of pitch, which serves also to guard the wood from the attacks of the acid. In the sides of this trough, and directly opposite each other, are two grooves, for the reception of a plate *(e f)*, of slightly burnt clay or unglazed porcelain, which is firmly cemented in its place, so that the two divisions of the trough, which it forms, may have no communication with each other. This partition must be of such a nature that it will permit a free passage for the electricity, although it must allow but a slight connection between the two liquids; and care must be taken that it does not become loosened or destroyed by the action of those liquids. I had, in the first instance, much trouble in procuring the necessary porous plates for the diaphragm; but at present I can get them of superior goodness at the stoneware manufactory *(Guntherschen Steingutfabrik)* at this place. I also considered attentively on the possibility of employing lime-tree, or some other porous wood, instead of clay, for the diaphragm plates, and proposed to myself some experiments for my instruction; but as these experiments were not continuously carried on, I am not prepared to shew whether or no any disadvantage would attend the employment of wooden diaphragms. The wood was previously boiled, for an hour at least, in water containing a little sulphuric acid. The liquid which I used in the copper cell, was a solution of sulphate of copper, well saturated by dissolving the salt in hot water. Since, however, in time, the solution must become feebler by the reduction of the copper, it is necessary to be prepared with a suitable stock of bruised sulphate of copper, to add to the liquid and keep up the point of saturation, and thus replace the copper which has previously left the solution. For this purpose we may employ a square box, *k*, fig. 21, made of thin boards, and pierced with several holes in the bottom and sides. In this box the bruised salt is to be placed, and hung in the cell of the reservoir, so that the liquid may wash the upper strata of the sulphate, where it is always less saturated than below.

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* Mr. De la Rue discovered this fact prior to December, 1836. See "Annals of Electricity, &c.," vol. vii., p. 434.—TRANS.

For the liquid in the zinc cell we use diluted sulphuric acid, or a solution of sal-ammoniac, common salt, glauber salts, &c. In all cases it is well to amalgamate the zinc plate; however, this is less necessary when solutions of any of the neutral salts are employed. This liquid must, now and then, be renewed, or at least be diluted with water; for, after a short time, it becomes pretty well charged with dissolved zinc, and finally crystallizes. For the purpose of discharging the liquids, such cell or compartment is furnished with a bent tube, as represented in the figure. These tubes are furnished with pliable caoutchouc joints, which are found very convenient.

The size of the trough or reservoir necessarily depends, chiefly, on the size of plates; however, it is well not to make it too small, because when we have a good quantity of liquid to operate on, the action is more equable and constant than it otherwise would be. Moreover, there is an advantage in having the reservoir of some considerable length, in consequence of having an opportunity of moving the plates to a greater or less distance from one another, so as to be able to regulate the action. We have seen, in a former part of this work, that the strength of the galvanic current is measured by the quantity of hydrogen gas developed on the surface of the copper plate; but, by the present arrangement, the strength of the current is shown by the quantity of copper which it reduces on the surface of the copper plate, and, consequently, takes away from the liquid. In order, however, to be certain of success, the liquid must always be kept completely saturated; to attain which, we must observe, that no more copper is reduced than is restored again by the dissolution of the bruised crystals in the perforated box; or, in other words, that the strength of the current with respect to the surface of the plates, should observe a fixed ratio to the dissolution of the sulphate of copper. A very exact indication of the process of reduction, with respect to the recognised regularity with which it ought to proceed, is the light-red, or flesh colour, of the reduced copper itself, which cannot easily be mistaken by any one who has once seen it. As soon as this colour gets darker, and begins to have a sooty brown colour, it is a sign that the solution is not retained at the required degree of saturation. In this case it is best to enfeeble the current, which, as we have seen above, can be accomplished by lengthening the conducting wire, or with the same length, but thinner; by removing the plates to a greater distance from one another, or, finally, by diluting the battery liquid with more water. Whichever of these means we avail ourselves of, the result on the current will be the same. In reference to the duration of action, it is advantageous to have a large quantity of the fluid, and to keep the plates at a considerable distance from one another. If the current be weakened by diluting the liquid in which the zinc is placed, it will be convenient first to diminish the solution of zinc previously formed. Now, although the precipitated copper is firmer and tougher, by a feeble current, or by slow reduction, there is a certain limit at which no reduction takes place; and on the other hand, there is also a practical view to be regarded, which makes it desirable to hasten the process as much as possible. Much may be accomplished on these points, by varying the dimensions of the perforated reservoir *k*, and the application of heat. It hardly need be mentioned, that instead of a wood box, one of glass or porcelain would be preferable; and it is not impossible that metal might be generally employed.

Instead of the before-mentioned reservoir, with a fixed partition, we may employ an earthenware vessel, which may be either round or flat-sided, as circumstances require. With a rectangular one, we may have three cells, and either one zinc plate and two copper plates, or one of copper and two of zinc. Fig. 22 shews this arrangement, where *a*, *b*, *c*, *d*, is the reservoir, and *e*, *f*, *g*, *h*, the porous earthen or clay diaphram or vessel, and Z, K, are the zinc and copper plates. I will observe, that the manufacture of rectangular porous vessels requires some trouble; but I was enabled to get them made, after some tedious labour which was bestowed upon them. They were burnt in a muffel.

Instead of placing the plates vertically, we may place them in a horizontal position, as shown by fig. 23, where *a*, *b*, *c*, *d*, is the reservoir; *e*, *f*, *g*, *h*, the porous floor or diaphragm; and K, Z, the copper and zinc plates respectively. We may reverse the order of the plates, and have the copper above and the zinc below the diaphragm; but this latter arrangement is not recommended, because it is subject to many practical disadvantages and inconveniences.

Instead of the separation of the two liquids by potters' clay or wood, we may, with more or less advantage, employ various other substances, such as stout bladder, English brown paper, leather, parchment, thick and close woven cloth, &c.

It is of the highest importance that we, in every stage of the process, are enabled to ascertain the precise degree of action in the apparatus. For this purpose, I usually employ a galvanometer, and ascertain the degree of action, and consequently the rate at which the copper reduces, by the deflection of the needle. This instrument may be constructed in a very simple manner, as shewn in fig. 24, where *a*, *b*, is a round board of hard and dry wood, furnished with three screws for adjusting it to the horizontal position. In the centre of the board is fixed a fine steel point C, on which is freely suspended a magnetic needle. Under the middle of the board is fixed a copper wire of about 1½ or 2 lines in diameter, the ends of which are furnished with two mercury cups, *d* and *e*: on the upper surface of the board is a graduated circle. The wire must pass directly under the steel point which supports the needle, and must be placed lengthwise in the magnetic meridian, when the needle stands at zero. If we connect the excited plates of the battery with the wire in the cups *d*, *e*, the needle immediately becomes deflected, and after several oscillations, will settle on some of the divisions on the scale. The diminution of this deflection shews a corresponding diminution of power in the battery. In this case we must restore the saturation of the cupreous solution, either by renewing it altogether, or by means of the magazine of crystals of sulphate of copper; or sometimes an accidental circumstance takes place which renews the action. Frequently the diminution of power is occasioned by the diaphragm being stopped with impurities, &c., in which case it must be removed, and completely cleansed from the saline matter which lodges in its pores. When the dimensions of the apparatus are considerable, we may convince ourselves of its activity by the spark which is produced on opening the circuit, or by its power of rendering a thin platinum wire red hot. However, these indications are always more uncertain than those exhibited by the galvanometer needle.

VII.

We see, from the management, that, however simple the process of obtaining galvanic copper plates may appear, it requires very much attention. We shall also find, by closer inspection, and especially by practical exercise in the art, that many interruptions take place, which it becomes desirable to remove; for, in the first place, as already stated, there is a limit with reference to the saturation of the cupreous solution, the strength of the current, and even in the time in which we can obtain the deposited copper plates. The great tenacity and firmness which the copper attains by slow reduction, is certainly a desirable property, though only of a subordinate consideration where it operates as an impediment to the acceleration of the arts.

If, by some oversight, the precipitated copper should become of a brown red, or be loose, a new layer, even from a saturated solution, will not attain the required hardness and colour. In such cases, the brown surface must be scraped off, or the whole plate be well washed over with diluted nitric acid. The most serious mischief, however, by the hitherto described method, is, that it is too much limited in its operations, both as respects configuration and magnitude of the plates produced; and, in order to obtain a constant and economical action, the zinc, and the original article to be copied, must have placed between them one of the described forms of diaphragms, which ought to keep the fluids separate, and yet keep its pores open so as to permit free circulation. When the impediments in this part of the apparatus are but trifling, they are easily removed; but when considerable, they are attended with many difficulties and inconveniences, and not easily got rid of. According to this first method, it is probable that the galvanoplastik art might have had but a very limited field of operation: at this stage, however, was the beginning of my troubles. Fortunately our success does not depend upon first efforts, nor ought we to consider that the impediments which first present themselves will eventually be of much practical consequence.

In order to comprehend upon what principle the second method depends, it will be necessary that I say a few words on the chemical action of the galvanic currents. It has already been stated, that within the closed circuit, and, it is true, in the cells where the excited plates are placed, there is a state of chemical activity. This chemical activity is not, however, limited to this particular part of the circuit, but allows of being transferred to any other, wherever we place an intermediate cell, filled with a conducting liquid, through which, by means of homogeneous metallic plates, the galvanic current can be transmitted. It appears from this, that nothing more is necessary to shew this fact, than that the metallic conductor, which goes from one pole of the battery to the other, should be somewhere interrupted by a liquid conductor. If we allow that the metallic plates, which are immersed in this liquid, are perfectly homogeneous, so that they cannot possibly excite a galvanic current, the following law invariably takes place:—*The hydrogen of the liquid, or the element which represents it, is developed at that plate which is connected with the zinc pole; and the oxygen, or its representative, goes to the other metallic plate, or that connected with the copper pole of the battery.*

The celebrated English philosopher, Faraday, has given to those plates, which are placed in the liquid to be decomposed, the denomination of *electrodes*; and, indeed, he names that plate which is connected with the zinc, the *cathode*, and the other, which is connected with the copper, the *anode*. In consequence of these abbreviations, we shall employ them in the remaining part of this work. Fig. 25: A B represents a galvanic battery; C D is a vessel nearly filled with diluted sulphuric acid, in which are immersed the two platinum electrodes, *a* and *c*. Of these, *a* is the anode, and *c* the cathode. If the current be sufficiently powerful, *c* will liberate hydrogen, and *a* will liberate oxygen. If instead of a solution of sulphuric acid, we place a solution of sulphate of copper in the decomposing cell C D, the laws of action will be such, that the plate *a* will, it is true, still liberate oxygen; but *c* will now become covered with a film of metallic copper; whilst the hydrogen, as has before been stated, will return to be employed in the reduction of the copper. If instead of the platinum electrodes, we place two copper ones, with diluted sulphuric acid, in the cell C D, the anode will develope either none, or but very little, oxygen; because, under these circumstances, it has a very great affinity for the copper, which it oxydizes‘ and then becomes dissolved in the sulphuric acid. The cathode will, at first, liberate hydrogen gas as usual, but the developement of this element will become gradually feebler, and shortly it will disappear, and in its stead the surface of the cathode will become covered with reduced copper in a loose brown-red condition. The fluid itself, which at first was clear as water, becomes gradually of the blue colour of the sulphate of copper. Although I carried on this experiment for several successive days, a slight developement of gas at the cathode was still discernable; which demonstrated that, by this apparatus, the reduction of the copper goes on only in an incomplete manner; even the precipitate does not become coherent, but granulous, which is probably due to the bubbles of hydrogen preventing the intimate connection of the cupreous particles. It is otherwise, however, when instead of diluted sulphuric acid, we employ an almost saturated solution of the sulphate of copper. In this case, however, the anode also dissolves, whilst the cathode bedecks itself with completely coherent clear red copper, as complete even as by proceeding according to the first method. The copper solution, by this means, continues in a state of saturation always proportional to the progress of reduction, by a supply of copper from the dissolving anode. A comparison of the weights of the plates shows, that the cathode obtains nearly the same quantity of copper as that which the anode loses. The small perceptible difference is too insignificant ever to become a consideration in a practical point of view.

Since by this arrangement of apparatus we are enabled to form copper plates in a vessel entirely separate from the battery, and entirely dispense with the large porous diaphragm used by the first described method, we arrive at an almost unlimited freedom in reference to the size and shape of the original from which we wish to take copies. Nor is the advantage less in reference to the time necessary for the operation, which by this means is much shortened; so that daily a film can be deposited of nearly a line or $\frac{1}{60}$ of an inch thick, and in many cases it will reach the thickness of a common card. To accelerate the reduction still more than this rate, appears not to be prudent, because of its affecting the firmness of the copper. When the current is sufficiently powerful to reduce two solotnik of one square inch in twenty-four hours, we obtain a loose incoherent product. It is possible, however, that by the employment of other salts of copper, we might obtain very different results.

It is a fortunate circumstance, that for the decomposition of the copper solution between the copper electrodes, a battery of one pair only need be used. We can, it is true, employ more pairs in series for the purpose of accelerating the action; in the meantime, it is to be understood these laws will take place, viz.,—in proportion as the pairs of plates in series are augmented, more zinc becomes consumed: not only in one cell, but in every cell in the series does this augmented action take place.

The copper solution which is placed between the copper electrodes must, to a certain degree, be diluted, which is best ascertained by experience. If, at the commencement, we employ a completely saturated solution, we shall observe, sooner or later, that the needle of the galvanometer indicates a tendency to return to the meridian, or at least it begins to be very unsteady. When this is the case, and the unsteadiness of the needle is not occasioned by any irregularity in the battery, we must dilute the solution with water until the deflection of the needle becomes more steady. It is sometimes useful to add to it a little sulphuric or nitric acid. The anode or the copper-plate that dissolves, generally becomes covered with a blackish or dark brown powder, which, if it falls down on the cathode, occasions the reduced copper to be brittle. This circumstance is easily avoided by placing between them a partition of flannel, linen cloth, &c. &c.

Notwithstanding the arrangement of this decomposing apparatus, no great difficulty is presented, since it can be disposed in many different ways; and as the most usual way is to place, in connection with the battery, the two copper plates, of any chosen form, opposite one another, in the decomposing cell, nearly filled with a solution of sulphate of copper, I shall, in fig. 26, shew the arrangement of the apparatus with those plates, arranged in horizontal positions. In this figure, *a*, *b*, *c*, *d*, represents a vessel or reservoir holding the sulphate of copper solution, furnished with a draining tube, which is not seen in the figure. This vessel may be of glass, porcelain, or even of wood, if made water-tight by a lining of asphaltum or resinous cement. We may also use lead or copper for this purpose, taking care to line such vessels with plates of glass or asphaltum cement; *e*, *f*, represents the cathode, which serves as an original to be copied, and whose surface is intended to be covered with the reduced copper. This plate, by the conductor *f*, *g*, *h*, is connected with the zinc pole of the battery, which, as already stated, may consist of a pair of plates, of small or large dimensions, according to circumstances; *i*, *k*, represents a flannel or linen partition, stretched on a wooden frame, on which the 'copper plate, *l*, *m*, is placed: this latter plate is connected with the copper side of the battery by the conducting wire, *n*, *o*. Instead of a whole plate, we may employ even single fragments, which ought to be so placed as to touch one another. In the circuit is placed the magnetic compass, *y*. Let me remark, in this place, that the process is not so satisfactory when the distance between the plates is less than about an inch and a half or two inches. When the dimensions of the plates are pretty considerable, for instance, a foot and a half or two feet square, the distance between them may be allowed to be three or four inches, which would not be too much.

The use of the compass is not sufficiently valuable to recommend in all cases; it will become directly useful, probably indespensable, when the galvanoplastic art has become a profitable source of employment. When this period arrives, it will be necessary, at least advisable, to prepare a number of these simple instruments at the commencement of any extensive process. If we combine several decomposing apparatus, of equal or nearly equal dimensions, and the same number of single batteries in series, in the galvanic circle, we have no need of more than one compass; as may be understood by inspection of fig. 27. By this arrangement, nearly the same weight of reduced copper will be found on each plate, at one and the same time. This circumstance also takes place even when the plates are of unequal dimensions; so that the thickness of the films obtained are inversely as the surfaces of the plates. From the laws exhibited in a previous part of this work, it is obvious that the smaller the decomposing apparatus, the greater the resistance to transmission.

We also enfeeble the current, and check the reduction of the copper, by combining together a great number of plates in the decomposing cells. Nor is it advisable to combine many decomposing apparatus together with one battery, as represented by fig. 28, because the distribution of the action is not proportionate to the whole force employed; and they are also liable to many accidental circumstances not easily avoided.

By this second method, we must employ galvanic batteries that will afford a constant action, such as those described in section 6; or at least formed upon the same principles, having a diaphragm for the separation of the liquids with which it is charged. The manifold and various kinds of arrangements that I have hit upon, whilst pursuing other applications of galvanism to a certain extent, I shall describe on another occasion; nevertheless, I shall give a representation of one battery in this place. In fig. 29, *a*, *b*, *c*, *d*, represents a rectangular copper or leaden box; *e*, *f*, *g*, *h*, is a cylinder, also of lead or thin sheet copper, which touches three of the sides of the box. It is better to leave the cylinder open at the side, than to solder or rivet the edges of the sheet together, in order that it may be easily opened and bent, so as to remove the reduced copper with which it soon becomes covered; *i*, *k*, represents a cylinder of potter's clay, and *l*, *m*, a cylinder of zinc, which may be either solid or hollow; *n*, *o*, is a small box of either lead or copper, perforated at the sides and bottom like a sieve. It is for the purpose of holding bruised crystals of sulphate of copper. When the liquid is wanted to be let off from the apparatus, we can use a flexible tube such as has already been described. Usually, however, I employ another contrivance for this purpose, which operates upon the principle of the syphon, and which I will here explain. It may be employed for many other purposes, and, I believe, in this form it is quite new. In fig. 30. *a*, *b*, *c*, *d*, is a vessel, with its draining tube *e*, *f*, which passes through the bottom of the vessel, and whose upper orifice is on the same level as the surface of the liquid; *g*, *h*, is a tube, closed at the upper and open at the lower end. This I call the *inverted tube*, (*Stülprohr.*)* The inner tube will discharge the most diluted part of the cupreous solution, by its overflowing at the top, when the outer tube is not in its place. If we use an apparatus to which no perforated magazine of crystals is attached, it will be necessary to employ a funnel with a long neck, when a new supply of the saturated solution of sulphate of copper is wanted, for the purpose of placing it at the lowest part of the apparatus, and thus lifting the old liquid so as to run off. If the whole of the liquid is to be discharged, the *inverted tube*, after being filled with liquor, is to be placed over the inner one, as seen in the figure, and thus the syphon is formed, through which the whole of the liquid which stands above the lower end of the inverted tube will become discharged.* It is scarcely worth mentioning, that the space between the top of the inner tube and the outer one must not be too small for the free flow of the liquid between them. When every part of the apparatus have the proper proportions, the discharge of the liquid need not depend upon its surface being above the level of the upper surface of the inner tube, because, by a motion up and down of the inverted tube *g*, *h*, the tube *e*, *f*, is easily filled, and the syphon thus brought into full play. This contrivance is very convenient for the purpose of charging several vessels at the same time: the inverted tubes are all arranged and fastened in a frame, in order that they may be let down at once. The discharging tube, *e*, *f*, must not be too wide, so that it may easily get filled. The solution of zinc will gradually become more and more saturated, if care be not taken to remove it and add water in its place, which must always be attended to. It may very easily be diluted, by pouring fresh water to the bottom of the vessel through a long-necked funnel, by which means the newly-added water gets beneath the saturated solution and lifts it up, mixing, at the same time, to a certain extent, with the lower strata. If it be thought proper to remove the whole of the zinc solution, the porous vessel must be taken out, and its contents poured off, which is but seldom necessary, as may easily be shewn by fig. 31, in which is seen a syphon, similar to the former, for removing the solution of zinc when required. The bottom of the copper vessel, *a*, *b*, *c*, *d*, is furnished with a small attached tube, in which another tube, passing through the bottom of the porous cylinder, *e*, *f*, *g*, *h*, is placed and cemented. Into the upper orifice of the latter is cemented a glass tube, *i*, *k*, *l*, *m*, whose upper end reaches to the level of the surface of the liquid. Both this and the outer tube, *n*, *o*, *p*, *q*, are best made of glass, and fastened, by some means, so as to prevent derangement by agitation; also constantly left open, so as to be ready, on all occasions, to let the old liquid run off in the direction of the arrows, when fresh supplies of saturated solution are introduced. Should it be desirable to remove the whole of the liquid, the last-named tube may be taken off, and replaced by another, similar to the inverted one *g*, *h*, in fig. 30, by which means the discharge will be as complete as by the former method. If there be sufficient room in the porous cylinder, *e*, *f*, *g*, *h*, the inverted tube may be sufficiently large to be placed over the outer glass tube, without removing it from its place.* At an early period I employed an arrangement which I shall describe at another convenience. I may here state, nevertheless, that the one now described stands next for convenience and simplicity. There remains to be made known, however, that by this arrangement there is one disadvantage experienced, by our not being able to renew the porous vessel without interrupting the action of the whole apparatus: and it is necessary, now and then, to change these porous vessels, and soak those last used in clean water, in order that their pores may be well cleansed of the crystallised salts that lodge in them. This process will occupy five or six days, according to circumstances; which, however, I have found is a sufficient length of time, even after I have kept a battery frequently from fourteen days to three weeks in uninterrupted activity, and in such uniform action, that the small deviations in the direction of the magnetic needle, and variations of temperature (*Temperaturveränderimgen*) in the liquids, were too trifling to describe.

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* This word might be translated *capped tube*, but I have chosen *inverted tube*, as more likely to be understood.—TRANS.

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* This contrivance, although new to our author, is very old in this country. The syphon in *Tantalus's Cup* is very often made in the same manner.

The size of the apparatus here spoken of becomes limited, in consequence of the difficulty in procuring porous cylinders of considerable dimensions, and at the same time having thin sides or walls. Thick walls offer a considerable resistance to the currents, and consequently lessen the action. It is, therefore, preferable to unite several smaller apparatus into one common action, by connecting all the copper cylinders together on one hand, and all the zinc cylinders on the other, so that they may form but one voltaic pair. Fig. 32 represents a ground plan of an apparatus of nine elements, placed in one common reservoir, and which can be properly united by clamp screws, or by any other convenient method, so that they may form *one single pair*, of nine times the surface presented by each individual element. The method of combining the metals is not shewn in the figure, in order to prevent confusion. It is true, this apparatus requires much liquid to keep it in action; notwithstanding, however, it is so much the more durable, and is easily managed.*

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* We are of opinion that our author has made his apparatus rather too complex to become of general use.—Trans.

For whatever purpose the galvanoplastik art may be used, we shall see, by what follows, that it is capable of very extensive application. The hitherto known methods of obtaining metallic copies, by casting or stamping, may be entirely superseded by this process; and the certainty, sharpness, and accuracy, in every case, is such as by the old methods could not be accomplished; and in regard to the beauty of polish, it surpasses coins or medallions from the finest steel dies. If we take a plate of gold, silver, or copper, of the highest polish, and employ it as a cathode in the galvanic circuit, the copper that becomes reduced upon it, not only exhibits the exact polish of the original, but it finds out the finest microscopic scratches which the polishing process left unfilled up. If we touch with the finger a highly polished plate of metal, a small dull speck, which shews the pores of the skin, will be left behind; even this speck will be so accurately copied by the galvanic process, that the keenest microscopic observation can detect no difference from the original. It is well known, that to obtain metallic copies by striking with dies is a very expensive process, and the truth of the original is always encroached upon; but by the galvanic casting the most accurate copies are produced at a very trifling cost.

When we are about to multiply copies from a deeply engraved plate, we must, in the first place, make a galvanoplastik picture, *in relief*, of the original engraving; and upon this first galvanoplastik we can again, at pleasure, obtain other plates, which will be precisely identical with the original; and they may be printed from it in the same manner, and the impressions will be as good as those taken from the first engraved plate. I will also make a few remarks in this place respecting the separating of the galvanoplastik from the original plate. The two will always separate very well, when the new plate is allowed to become sufficiently thick, if the copper of the original be not spongy, porous, or scaly, and, finally, if the design be not engraved too perpendicular, or, rather, be not undercut. There are essential circumstances to be attended to in all cases where engraved copper-plates are intended as models for forming galvanic copies on.

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* There are a few more lines of this section, which it would be useless to translate, as they merely refer to the supposed cost of keeping up the action of the apparatus in Russia, by turning to account the sulphate of zinc and other products. —TRANS.

If the galvanic copper be slowly and cautiously reduced, it attaches itself very excellently to every part of the engraved plate, and allows of being easily loosened. There is no difficulty whatever in making galvanic plates, especially where an already engraved copper plate serves for the original. By this means we get rid of the tiresome labour of grinding and polishing, requisite processes which the original engaved plate has already passed through; at the same time, such original plates should have obtained an uniformity of texture which surpasses that possessed by the best mercantile copper. With common copper, it frequently happens that the galvanic plate adheres so firmly to the original, if not throughout the whole surface of contact, at least in many places, that the separation of them can be accomplished by no other than forcible means, and it is possible only at the expense of the original. Sometimes a thin film of fat, or oil, laid over the original plate, prior to its being submitted to the galvanoplastik process, facilitates the separation of the two. Strong coverings of wax, lac, &c., can only be used where sharpness and accuracy is not of much consequence. The galvanic plates are easily removed from silvered or gilt plates, on which they have been formed. It appears, also, that for this purpose the gilding performed by the wet process has an advantage over that in which the amalgams of gold are used. An exposed covering of thin gold leaf, or gold size, over the face of the copper, answers, also, to facilitate the separation, and may be used for that purpose, where it can be done without injuring the sharpness of the design. These precautionary measures, after all, are not necessary when the copper of the original is of a good quality. As soon as the galvanic plate has acquired the requisite thickness, and the parts grown over the edges of the original are filed away, it springs loose of itself, without any further trouble. It hardly need be mentioned, that a casting of gypsum would answer all the purposes of copper plate, provided it were nicely managed, and taken from an original engraving that was not under-cut.

VIII.

In the preceding articles we have spoken of the reduction of copper on *copper* plates only, and have stated that the application of the galvanoplastik art would be very limited, if the process could not be extended to originals of other metals; to all those metals, for instance, that would not of themselves decompose the copper salts; that is, those which would not dissolve when placed in the cupreous solutions, and precipitate the copper therefrom so as partly to be covered by it. Those metals which sufficiently resist being attacked by the copper solution, are iridium, platinum, gold, silver, quicksilver, arsenic, bismuth, and antimony; and, on the other hand, the copper solution becomes easily reduced by lead, tin, iron, and zinc. It may here be remarked, that pure and bright lead operates very differently to that which is tarnished. In the first condition it reduces the copper upon itself; but when in the latter condition it scarcely acts upon copper solutions: so that tarnished lead answers almost as well as copper for receiving deposited copper by electric currents. Moreover, although pure lead corrodes a little at the commencement, that action very soon disappears, and in a short time a thin film of copper forms on its surface. By means of this metal, then, we may proceed at once to multiply engraved copper plates without the originals ever entering into the galvanic process. For this purpose a sheet of lead is laid over the original engraved copper plate, and both passed through a strong rolling press; the lead is thus pressed into the engraving, and, when separated, presents a beautiful picture of it in relief. The leaden impression then serves as a form on which a fac-simile of the original engraving can be deposited by the galvanoplastik process. I have seen galvanic copper plates made by these means, which, for sharpness and accuracy throughout, were not surpassed by those deposited on copper plates made by the relief engraving machine.

Pure tin, by the action of cupreous solutions, becomes more corroded than lead, and thus presents an obstacle to its employment where the sharpness and purity of the original picture of the engraving is to be preserved; but answers well enough where those particulars do not interfere with the object of the operator. The dissolution of tin discontinues, however, as soon as, either by chemical or by galvanic means, it becomes covered with a film of copper. Alloys of tin, when this metal is not in excess, with those metals on which cupreous solutions have no action, even including lead, answer very well for patterns on which the copper is to be reduced; the proportions may very easily be determined by experiment. The type-metal, and also the well known fusible metal, are very applicable to this purpose.

It is well known that iron precipitates copper from its solutions until it has gradually and completely decomposed them, and the dissolution of the iron is not stopped by the formation of the loose copper covering that first forms on its surface. When the copper solution is saturated and contains free acid, the metallic copper falls down in the form of a powder; and although the precipitation is slower as the solution of the copper salt is more diluted, yet the metallic copper is so much the firmer cohered, that it very frequently becomes a firm mass, whose shape corresponds to that of the immersed piece of iron. The copper thus reduced by iron is well known by the name of *cæmentkupfer*, and is distinguished by its purity. In many places, where natural cupreous waters are abundant, this pure copper is obtained in great quantities. In Schmölnitz, in Upper Hungary, from 7,000 to 8,000 pounds of pure copper are obtained annually, by placing pieces of any kind of raw iron in the water naturally impregnated with the metal. I will here just remark, that this kind of chemical reduction as precisely differs from the galvanic reduction, as the chemical dissolution of zinc from its galvanic dissolution, which has already been alluded to in art. 1.

Zinc, as a model for galvanoplastik formations, is a metal that cannot be used, and it appears hitherto that its alloys with other metals are also exceptionable ; such, for instance, is the case with brass. This alloy, it is true, by an interworking of galvanic currents, becomes overlaid, in a short time, with a beautiful film of copper ; but it is always difficult, and often almost impossible, to loosen it even when grown to considerable thickness. But should we eventually succeed by the application of a strong force, we immediately perceive that the torn off piece of copper is covered over with a coating of brass, as though it were plated with that metal.

As regards the non-metallic bodies, with reference to their practical applicability, charcoal, and indeed in its form of graphite (plumbago), ought to be particularly mentioned. These substances will on no account affect the solutions of cupreous salts, and are capable of being employed to advantage, even better than platinum, in galvanic series, as cathodes in the galvanic decomposition of such solutions. Since, however, these substances present considerable difficulty in giving to them regular artificial forms, we must apply them in another manner, which, as we shall see, can be done to some advantage.

We have already seen that the galvanic action depends, principally, upon the *extent* of the metallic surfaces brought into a state of activity, and but very little on the thickness of the metal. From this fact we easily understand that such non-metallic substances as will not dissolve in the liquid, if covered with a thin metallic film, or with a coating of graphite, will answer all the purposes of metallic originals.

Hence it is, that any non-metallic mould or pattern being so covered, and, by means of a suitable conducting wire made the cathode of a battery, will receive the reduced copper from the solution, which will cohere firmly together and form an exact metallic copy of the original from which the non-metallic mould was taken. The non-metallic substances which may be employed for this purpose, are clay or porcelain, slate, plaster of Paris, bees-wax, sulphur, stearine, sealing-wax, wood, &c., either in plates or any other artificial form. Any of these bodies employed as moulds or patterns, are to have their surfaces covered with thin metallic leaf, or with soft impalpable metallic powders, or with powdered charcoal or blacklead; which, in order to prevent the fine lines and angles of the mould or pattern being blunted, must be laid on carefully and exceedingly thin. It will be obvious that these foils or powders can only be of such metals, as has already been observed, as will not of themselves chemically decompose the cupreous solution. We may obtain powders for this purpose ready prepared in the shops, or we may easily prepare them ourselves. For instance, we obtain a very soft powder of copper by precipitating it from its nitrous solution by iron. Besides the metals, we may also prepare plumbago in a finely washed impalpable powder, which is much finer distributed, and attaches itself to the face of the mould much better than any of the metallic powders. When thus prepared, it may be mixed with water and gently smeared over the model. When the film of plumbago has become perfectly dry, should there appear a superabundance on any part, it may be removed by a soft pencil or brush. The plumbago will adhere well enough to some substances without being moistened with water, and may then be laid on dry by means of a soft pencil, which, previously, has been made a little clammy with oil.

If the model or pattern be of plaster, it ought to be so prepared as to resist the introduction of the liquid for a long time. This property is best acquired by placing the plaster mould in a hot mixture of stearine and wax, and permitted to soak as long as air-bubbles are seen to ascend in this pure liquid. By this means the mould acquires a considerable degree of hardness, without losing any of the original sharpness of the design.

I have previously alluded to stearine as a substance which, when clothed with a metallic surface, can be employed in the galvanoplastik art. In again referring to this substance, I will here add, that when managed with caution it produces castings from the softest design, which, for accuracy and sharpness, far excels any plaster casting whatever. My attention was first directed to this property of stearine by Count Alex. Bobrinski, to whose circumspect enterprising spirit, in spreading knowledge and promoting industry in his native land, so many are grateful. The stearine, moreover, is susceptible of being well polished, turned, and, as it appears, of being engraved on—properties, in consequence of which, for this purpose, as well as in other respects, this material commands a high importance.

In the employment of non-metallic substances, some foresight is requisite in the application of the conductors which unite them to the zinc pole of the battery. However finely and equally the metallic powders, or the plumbago, may be distributed over the face of the mould, or pattern, they produce only an inferior conducting surface ; and the reduction commences at those points only where this inferior conducting film is in intimate contact with the uniting conductor ; and, consequently, the more we increase the points of contact, so much quicker will the surface of the mould be covered with reduced copper. I usually surround the model with a thin strip of rolled lead or copper, which easily bends to inequalities of the margin, and allows of being brought into intimate contact with the metallized or graphitized surface. It has still to be remarked, that the reduction proceeds with an uniform distribution, when we glue the original in a horizontal position, which position is particularly recommended, when the surface to be covered is of considerable dimensions, and in bold relief. All those parts which are intended not to be covered with copper—such as the connecting metal, the back part of the pattern, &c.—must be covered with wax, or other non-conducting substance, sufficiently to prevent any bare metallic parts being exposed to the cupreous solution ; for, wherever there is an unnecessary deposit on such parts, it interferes with the action on the face of the model or pattern, and prevents the galvanic copy from arriving at the intended thickness. But we can, even under these circumstances, increase the thickness of the copper plate, especially where malleability is not a particular object. This is accomplished by strewing copper, in fine corns or filings, on the top of the first formed galvanic casing, which will very soon grow firmly to it, and become of the self-same piece.

IX.

The great variety of substances, partly plastic and partly otherwise manufactured, which can be employed in the galvanoplastik process, opens in this novel art, which may be considered as a *cold metallic foundry*, a field of infinite extent and interest, not only to the artist, but also in many other practical points of view. I will just point out a few instances of its practicability, which I have convinced myself of. Of the manner of copying engraved copper plates I have already noticed, and I will now add, that the same process is no less applicable to copying of medallions, coins, &c., whether of copper or of the noble metals. The galvanoplastik process can also be applied to the formation of matrices for single letters, or for entire stereotype plates; and again, the types themselves may be deposited in these matrices; or they may be used in the usual way as moulds for casting the letter type metal in. Whether copper stereotype plates will deliver a greater number of sharp printed copies than can be obtained from the common type metal, is a question that can be determined by experience only. The pictorial stamps surrounding initial letters, and other typographical ornaments, and also those tools which bookbinders use, may, in future, be very easily made by the galvanoplastik process. The patterns may first be cut in wood, from which copper matrices may be taken; and from these again the required copper types will be easily obtained. Forms for tapestry and cotton prints are easily made by the same means, which affords an opportunity of their being procured in great variety, and to any extent. Maps and plans, *en relief*, of towns, have recently come into considerable repute, for the printing of which, the necessary forms and counterforms may be immediately obtained by depositing the copper, to the required thickness, upon a proper mould or pattern made of any suitable material. Bas-reliefs, and other objects in relief in the arts, can be immediately formed in copper in infinite variety, upon wax embossed originals, even, perhaps, without the aid of the chisel; and, indeed, with all the sharpness and delicate softness that the original received from the hand of the artist.

You have already been made to understand that the first form for all these purposes can be taken in plaster moulds. This substance is also applicable, in a similar manner, for obtaining metallic forms or moulds for the manufacture of stone-ware pots, and the pottery ware which are decorated with relief figures. The galvanoplastik process, moreover, places in our hands the means of decorating our buildings, both interiorly and exteriorly, with cheap and numerous copies of the finest specimens of ancient bronzes; and, as it were, opens an entirely new and extensive field for the cultivation of one of the finest branches of the arts.

That objects composed of inferior materials may, by this process, whether for protection against the weather or for other purposes, become covered with copper, is a circumstance worthy of mention in this place. By the galvanoplastik process, notwithstanding the accuracy with which we procure copies of original objects, we see that on the reverse side of the galvanoplastik copy the deposited metal assumes a granular appearance, and it is only when the process is carried on very slowly, and the layer of copper is left quite thin, that there is any appearance of the outside of the copy having any corresponding features with the original. Notwithstanding, however, the partial inaccuracy at which we can only arrive by this method, objects thus overlaid with copper, when seen at a distance, will still present to the eye the true figures and proportions. They may be covered with a metallic skin of any required thickness, and any bold protuberances or other accidental roughness that may form can easily be removed by the chisel.

Hitherto I have treated only of such galvanoplastik processes as are applicable to obtaining simple copies from original forms or matters from which they are easily separated; for instance, from engraved copper-plates, coins, medallions, seals, wood-cuts, &c. Were we to aim at the manufacture of entire figures, such as statues and other entire objects, for which a complicated mould, consisting of several pieces, would be required, the difficulties attending the process would be much greater than in those simple cases hitherto described: nevertheless, in the most complicated cases, the difficulties that would probably be met with do not appear to be insurmountable. From a wax embossed bust, *en haut relief*, and much underworked, I have obtained a tolerably good galvanoplastik figure, though, it is true, not entirely free from blemish, in the following manner:—The original wax bust being well covered with plumbago, and furnished with a conductor, was submitted to the galvanoplastik process. When the whole had become covered with a thin skin of copper, the wax was melted out, leaving a hollow copper mould corresponding to the original wax figure. After washing out this mould with spirits of turpentine, it was again submitted to the galvanic action, as a cathode, in order that the precipitation might proceed within. When the process had continued long enough for the interior figure to be of the required thickness, the outer case, which had served as a mould, was loosened, and removed piece-meal, which, in some places, could not be accomplished without some degree of force. By these means, however, I obtained a true and perfectly smooth copy of the original, which in some few places only was a little deranged, from causes that may, in future, be avoided. It is true that by this method we lose both the original and the first formed metallic mould in every copy that we obtain; but it is to be hoped that this circumstance will be no hindrance to the diffusion of the advantages to be gained by the galvanoplastik art, from which so much may reasonably be expected, and in which process the workshops and laboratories of the artist and the handicraftsman will still be productive of many accomplishments and facilities, which, as yet, can only be viewed in prospective.

THE END.

J. LEICESTER, PRINTER, ST. ANN'S-STREET, MANCHESTER.

NOTICES OF OTHER WORKS,

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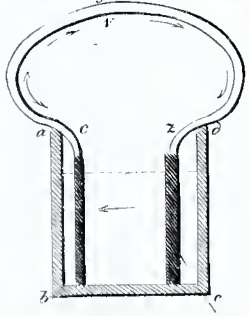
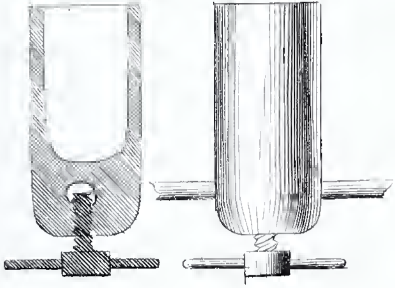


Fig 2



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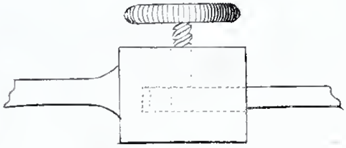

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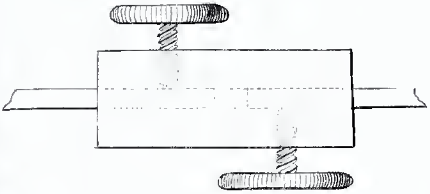


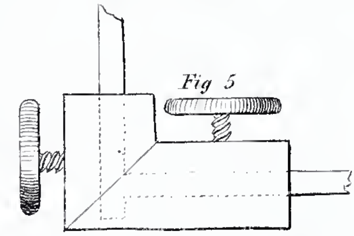
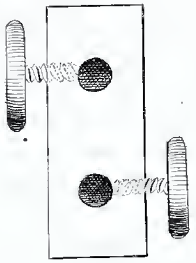


Fig 5

Fig. 6



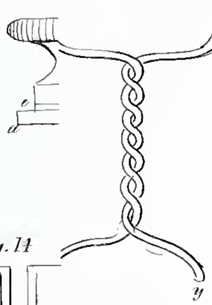
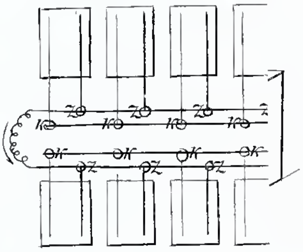


Fig. 14



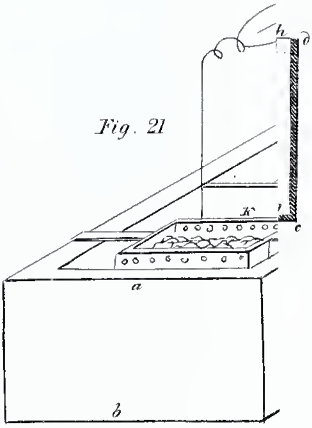


Fig. 21

Fig. 2

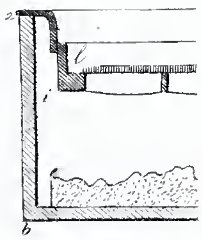
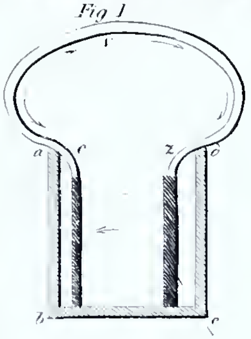


Fig 1



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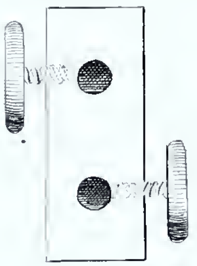

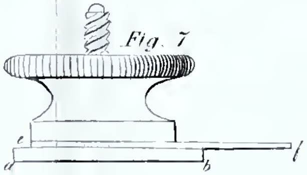

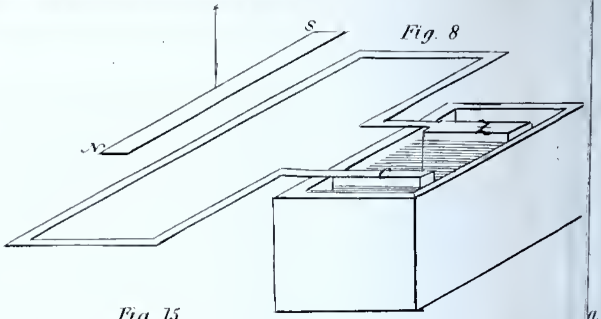

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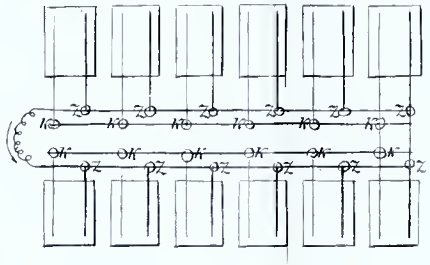
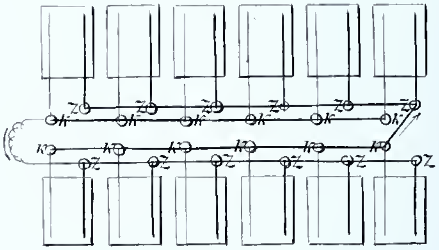


Fig. 15



g. 16

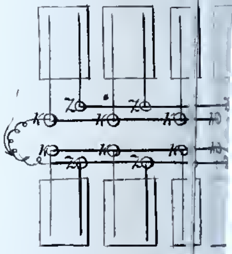


Fig 2

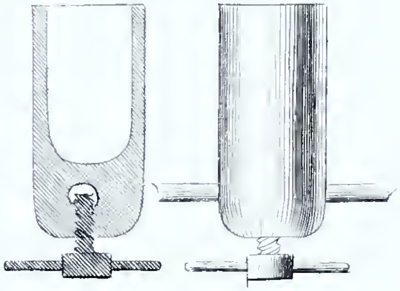
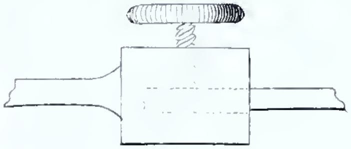


Fig. 3



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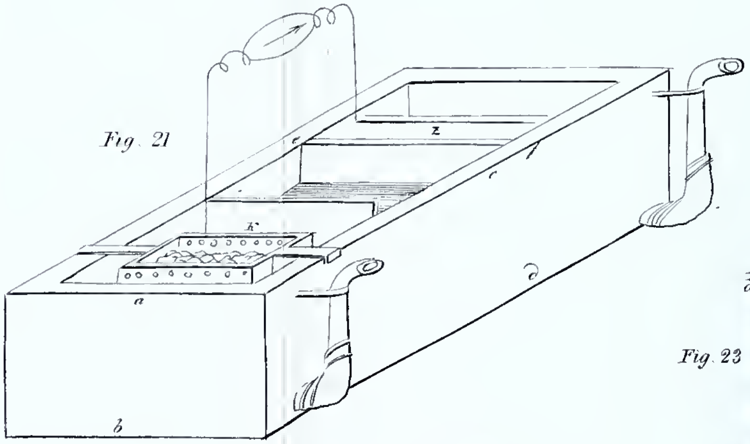
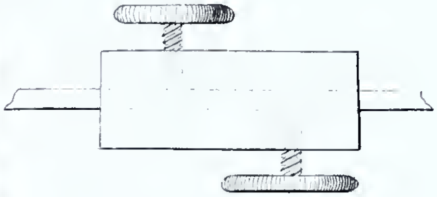


Fig 4



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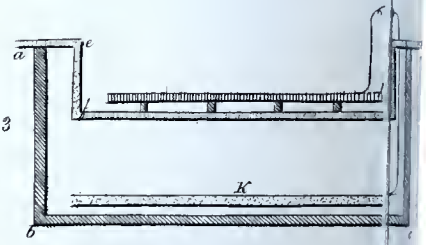


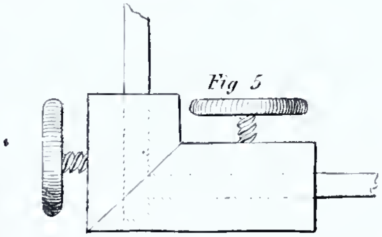
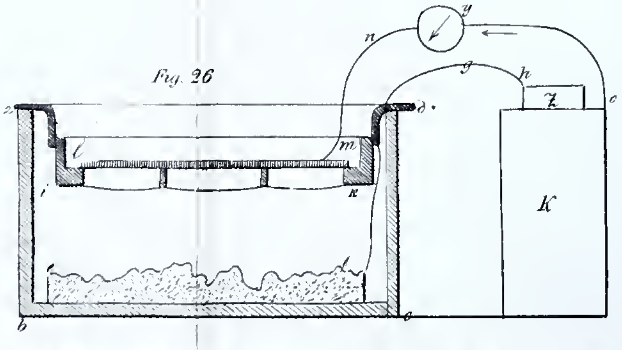


Fig. 26



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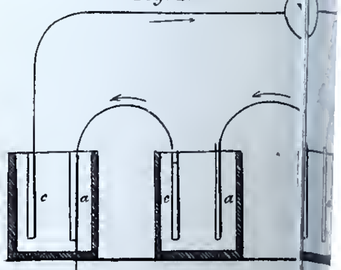


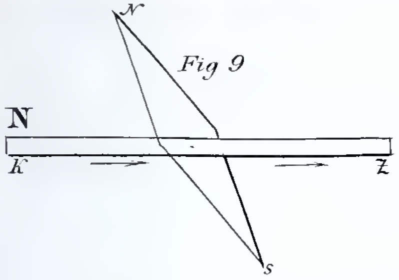
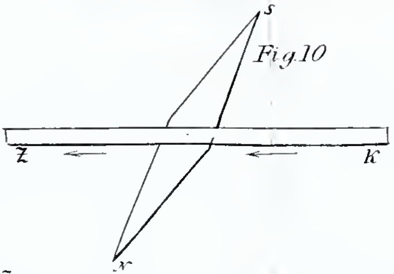


Fig 9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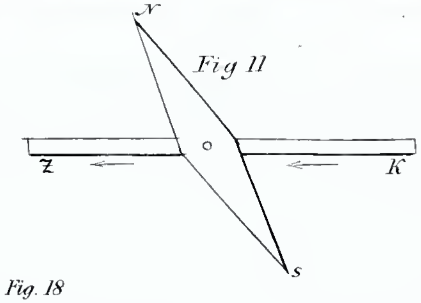
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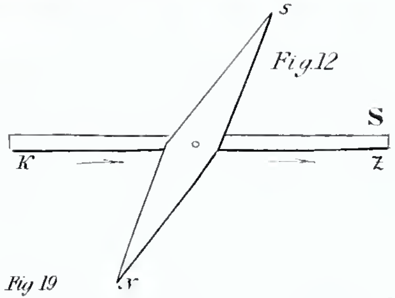
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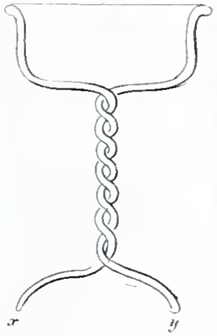
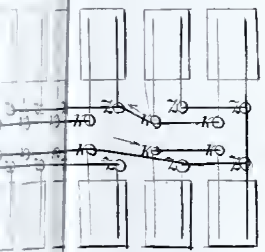


Fig 13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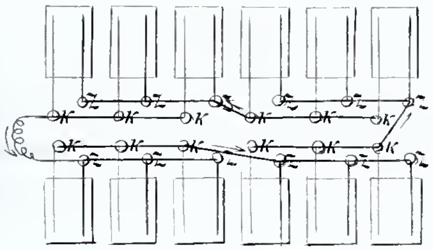
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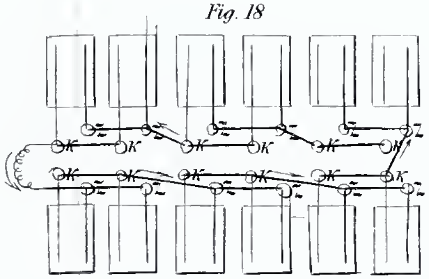
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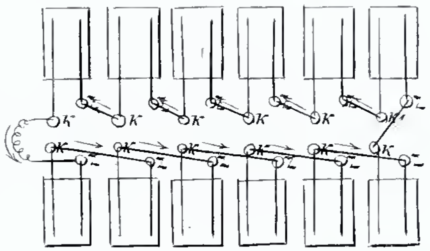
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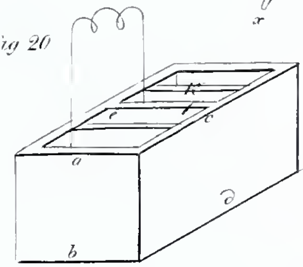
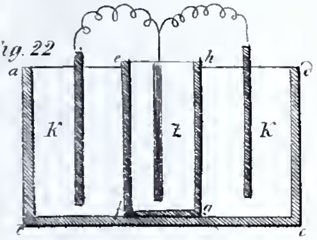


Fig 20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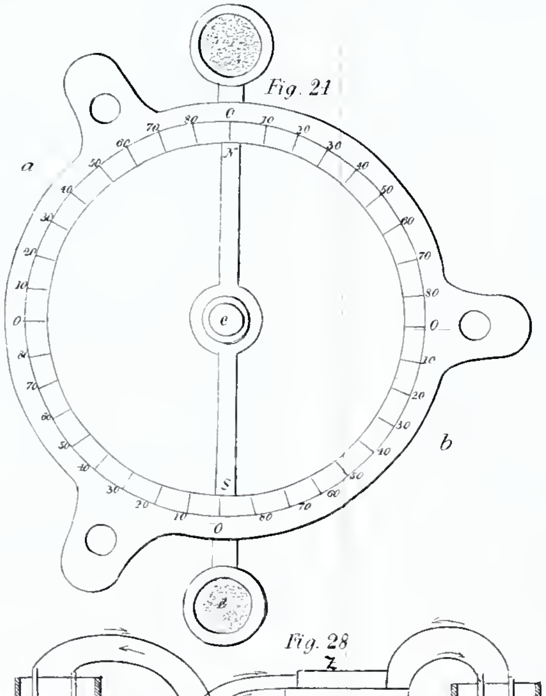
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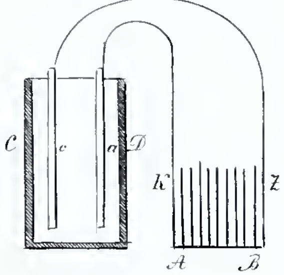


Fig 25

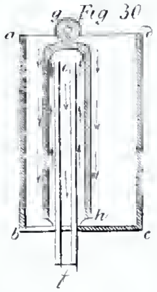


Fig 30

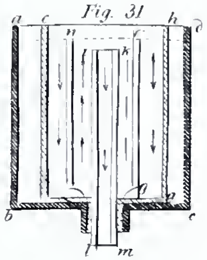
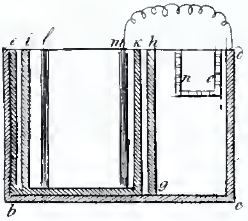
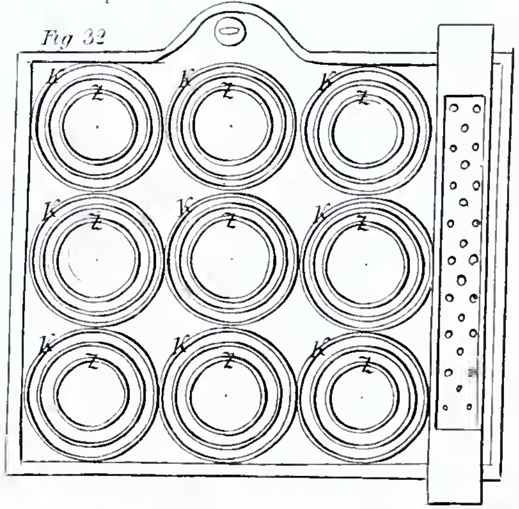


Fig. 31

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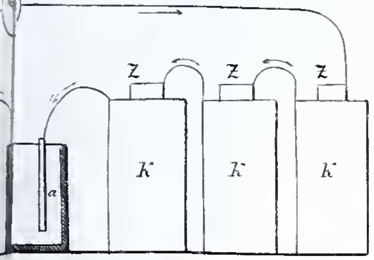

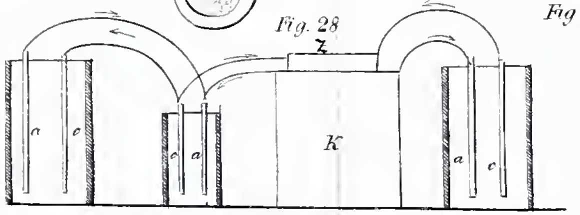
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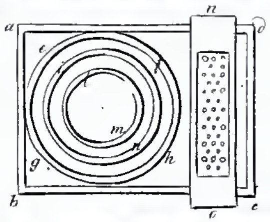
Fig 29